MECHANICS

UDC 631.31:681.2.083:631.421 https://doi.org/10.23947/1992-5980-2020-20-1-5-14

Research and modeling of a multilayer composite material using basalt fabric

A. Karnoub[1], D. B. Nezhizhimov[2], K. S. Shirinyan[3]
[1] ETH (Zurich, Switzerland)
[2, 3] Don State Technical University (Rostov-on-Don, Russian Federation)

Introduction. The range of use of composite materials (CM) is constantly expanding, finding application in many areas of mechanical engineering, agricultural technology, aircraft manufacturing, instrumentation, shipbuilding, in the manufacture of high-pressure containers, etc. Quite often, multilayer composites consisting mainly of one type of reinforcing material and a binder are used. Of particular interest is the use of various types of reinforcing materials – more durable in the places of maximum stress in the cross section – in a single composite. As an example, we can use glass and basalt fabrics and fibers using one type of binder. The work objective is to study properties of such a material and to model it using the finite element method.

Materials and Methods. The components used are commercially available. BT-11 basalt fabric, TR-0.5 fiberglass, as well as glass mat with a density of 300 g/m^2 were used as reinforcing materials. An epoxy resin of the ED-20 grade with a PEPA hardener was used as a binder. Two types of material were also manufactured for tensile and bending tests, respectively, the differences of which consisted in the number, type and layer sequence. For modeling, CAD COMPASS 3D, APM-FEM module was used.

Results. Basalt fabric is used in the outer layers of the composite material, fiberglass – in the inner layers. This approach provides increasing the tensile strength of the composite during tensile and bending; however, critical failure leads to an instant loss of the bearing capacity of the material. The use of glass mat as the core of the composite material showed lower allowable stresses, both tensile and bending; but in case of bending, it turned out that when the material was delaminated, the load-bearing capacity of the material was about 10% of the maximum. Modeling of the material is possible with some assumptions, in view of the size of the final elements.

Discussion and Conclusions. The use of basalt fabrics as a reinforcing material provides obtaining products with the properties of both glass and carbon plastics. Such a CM will be slightly more expensive than fiberglass and much cheaper than carbon fiber. Products made of composite materials (equivalent to isotropic materials) can be modeled in computer-aided design systems using the finite element method. It is important to consider the type of loading on the product, since CM mainly have anisotropic properties (the load is applied taking into account the direction of fibers). In multilayer CM from structural fabrics, it is necessary to direct the loads along the fibers. In addition, it is necessary to consider the interlayer shear, different adhesion between the layers, etc. The main assumption of this method is the "constancy" of the material thickness, the number of layers and the order of their location.

Keywords: composite material, basalt fabric, fiberglass, glass mat, finite element method.

For citation: A. Karnoub, D. B. Nezhizhimov, K. S. Shirinyan. Research and modeling of a multilayer composite material using basalt fabric. Vestnik of DSTU, 2020, vol. 20, no. 1, pp. 5–14. https://doi.org/10.23947/1992-5980-2020-20-1-5-14

Introduction. In the work, polymer composite materials (CM) with a reinforcing composition based on basalt and glass fabrics were studied and modeled. Epoxy resin was used as a binder. The 11- and 13-layer composites were investigated.

In [1], technological and other characteristics of the CM are noted, including those determining the load distribution in the layers. Here, the principle of “simple” modeling of composite material in various computer-aided design (CAD) systems is considered, as well as the behavior of CM depending on the type of loading.

A method is described for increasing the interlayer shear resistance in polymer CM by adding finely divided solid particles (for example, glass) to the binder[1]. The process of occurrence of interlayer stresses was studied [2]. It is possible that the application of this method would avoid stratification and increase the allowable stress of the samples.

In [3–5], the volume content of the binder, the methods of its application to the reinforcing material, the laying-up method, the operating procedure, etc., are determined.

It is known that the type of deformation and fracture of a composite polymer is determined by its shape, quality and binder (including its volume content)[2]. The corresponding dependence has been derived [6, 7].

In [8–10], modeling a part from CM using the finite element method (FEM) in CAD is described.

The paper presented also uses FEM. With its help:

- reliability of determining the stresses in the places of destruction of the samples and safety factors is validated,
- specifications of using assumptions that facilitate the calculation of products from polymer CM tested previously on tensile machines, are indicated.

In [11], the influence of the shape and type of reinforcing components on the thermal and mechanical properties of a polymer composite material is described.

In [12, 13], the applicability of composites in engineering, automobile production, construction, etc., were noted.

Research Objectives:

- to justify the use of basaltic fabrics in polymer CM,
- to determine their strength properties with various reinforcing components,
- to check the possibilities of modeling CM by the finite element method.

Materials and Methods

A composite material based on basalt and glass cloth and glass mat was studied in this work. As a binder, epoxy resin ED-20 with hardener polyethylene polyamine (PEPA) was used. The reinforcing agents were fiberglass TR-0.5, basalt fabric BT-11 and fiberglass with a density of 300 g/m^2. A feature of the experiment was the use of several types of reinforcing material in one composite at once.

Justification for the application of basalt fabric and finite element modeling. At present, CM rarely uses basalt fabric, although it possesses characteristics important for high-quality composites: high impact strength, high specific strength, heat resistance, environmental cleanliness, high resistance to corrosion and acid, low thermal conductivity, affordable price, radio transparency, and good sound absorbing properties. It is also worth noting that basalt is a rock, and its reserves are practically unlimited. In the production of basalt fiber, the rock is melted, threads are drawn from it, which are used to make fabric, roving, etc.). In terms of strength, basalt fiber is superior to fiberglass and approaches carbon fiber. The price of basalt fiber is slightly higher than fiberglass, but significantly lower than carbon fiber. This allows fabricating products of higher quality than fiberglass, but at the same time cheaper than carbon fiber. Of particular interest is the use of several reinforcing materials in one CM: glass and basalt fabric, as well as glass mat. When modeling composites in CAD, it is required to set materials with various characteristics, which creates known difficulties. In the framework of this work, the possibility of a standard study of structures by the FEM is determined.

[1] Nezhizhimov DB. *Sposob uvelicheniya soprotivleniya mezhsloinomu sdvigu v mnogosloinykh kompozitnykh materialakh* [Method for increasing interlayer shear resistance in multilayer composite materials]. In: Proc.3rd All-Russ. Sci. Conf., Kursk, 2019. P. 84–88.

[2] Antibas IR, D'yachenko AG. *Issledovanie protsessa razrusheniya sloistogo kompozitnogo materiala* [Study on destruction of the layered composite material]. In: Proc. 10th Int. Sci.-Pract. Conf. within framework of the 20th Int. Agroindustrial Exhibition “Interagromash-2017”, Rostov-on-Don, 2017. P. 179–181.

For this, anisotropic material is “equated” to isotropic, and the products are designed so that loads can be applied along the direction of the fibers.

The use of structural fabrics makes it possible to model the behavior of CM with some assumption. However, it is necessary to consider the type of weaving of fabrics and the angle of rotation between the layers. Thus, it is required to obtain the results of an experiment on determining the strength properties, and to find out the tensile and bending strength. Based on this information, it is possible to simulate the composite for these types of loading since the material continues to collapse after damage to the outer layer under bending and to the defective layer under tension. If there are no defects in the composite under tension, fracture mainly occurs in a dangerous section.

Preparing for the experiment. For the experiment, samples were made from composite material (Fig. 1).

a)

b)

Fig. 1. Test specimens: (*a*) bending; (*b*) tensile

In the first case (see Fig. 1 *a*):

- the type of laying is sandwich (symmetrical arrangement of layers in all samples),
- the total number of layers per sample (first outer, then middle, then inner) are indicated,
- 4 layers of basalt fabric (BF),
- 2 layers of fiberglass (FG),
- 7 layers of glass mat (GM).

In the second case (see Fig. 1 *b*):

- 6 layers of basalt fabric (BF),
- 5 layers of fiberglass (FG).

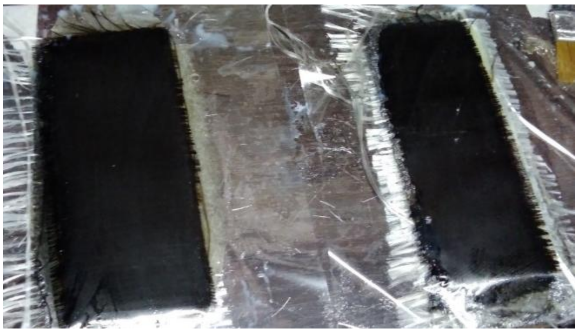
In both cases, the binder is ED-20 resin, the hardener is PEPA.

Thus, two types of material are obtained. Their differences allow you to check:

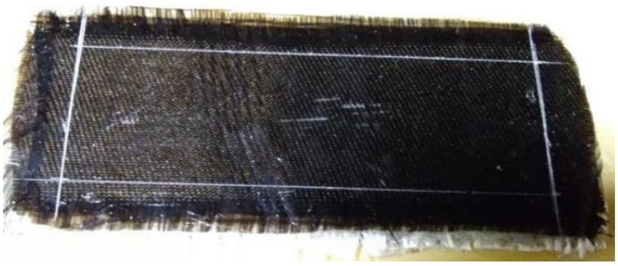
- if using fabrics with mats is worthwhile,
- what effects a combination of different types of materials will give.

Sampling. Samples were made through sequential placing of fabric layers (Fig. 2 *a*) on a base covered with a film, since there is no adhesion between the resin and the films.

a)



b)



c)

Fig. 2. Sampling: (*a*) material cutting; (*b*) removal of excess resin; (*c*) machine processing

After placing all the layers, they were heated and smoothed at the same time with a spatula through the film (see Fig. 2 *b*); in this case, a smooth surface without excess resin was obtained. Sampling scheme:

1) cutting samples with a margin for machining,

2) preparation of the foundation,

3) resin activation,

4) placing layers,

5) smoothing,

6) fixation,

7) curing,

8) machining (see Fig. 2 *c*).

Tensile and bending tests. Tensile and bending tests were carried out on a breaking machine (Fig. 3-5).

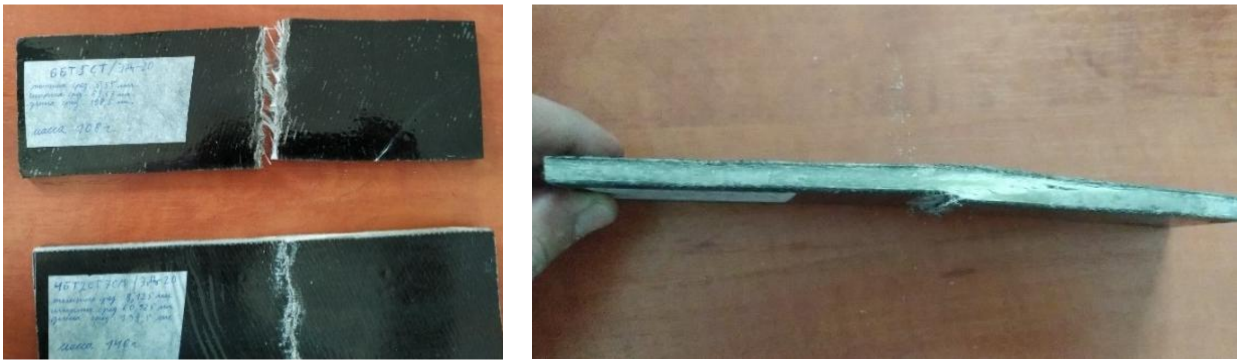
Fig. 3. Breaking machine

a)

b)

Fig. 4. Testing: (*a*) bending; (*b*) breaking

a)



b)

Fig. 5. Results of destruction of samples: (*a*) tensile; (*b*) bending

Research Results

Test Conclusions. Based on the test results, the following conclusion can be drawn: when combining fabrics and mats, a characteristic feature of fracture is delamination at the border of various types of material (see Fig. 5). When in comes only to tissue layers, such an obvious feature is not observed. Tissues used as reinforcing agents are torn at the place of maximum stress and then are sharply destroyed. Initially, individual fibers are destroyed, which is accompanied by a characteristic sound. Then the fibers are pulled out of the matrix — and the matrix itself is destroyed. This is shown by decoloration — the place of destruction "turns white" and looks more matt. The test results are presented in Table 1.

Table 1

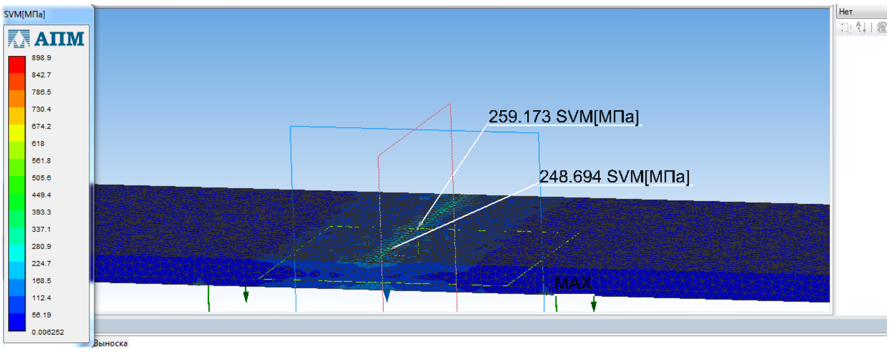
Characteristics of CM tested for bending and breaking

	6BT5ST/ED-20	4BT2ST7SM/ED-20
Max. bending force, kg	500	965
Max. breaking force, kg	3560	2600
Max. bending stress, MPa	265.1	239.5
Max. tensile strength, MPa	191.8	120
Sample parameters and distance between supports under bending, mm*	$b = 64.2$; $h = 5.5$; $L = 70$	$b = 61.7$; $h = 8.2$; $L = 70$
Section dimensions at break, mm	$b = 35$; $h = 5.2$	$b = 29.5$; $h = 7.2$
Density, kg/m^3	650	700
*Here, b is sample average width, h is sample average thickness, L is distance between supports.		

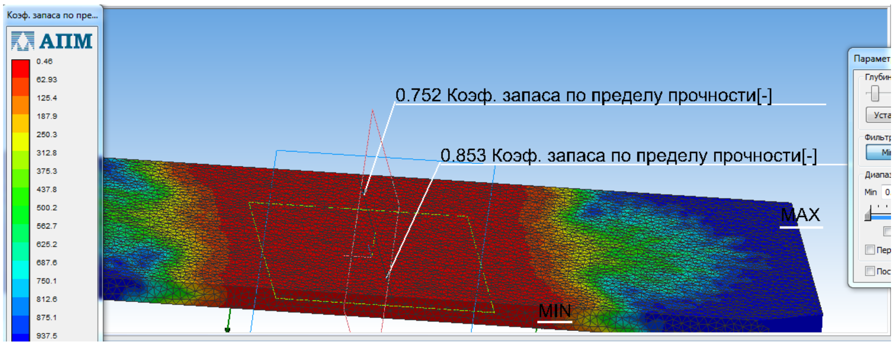
Composite material modeling and test validation. For modeling, the material 6BT5ST was selected. Its characteristics are included in the Compass 3D library, and solid models are created. Using the APM FEM module for

Compass 3D, finite element calculations were performed. In this case, difficulties arose due to the selection of the optimal sizes of the finite elements. The following assumptions were used for calculations: the fixing and load points were performed by slight stretching of the "strips" of 0.1–0.2 mm wide. In these areas, the results of stresses and safety factors should not be considered since they are incorrect. Such simplifications enable to apply loads and install fixation in any place on the models. The optimal mesh size is from 2 to 3 mm.

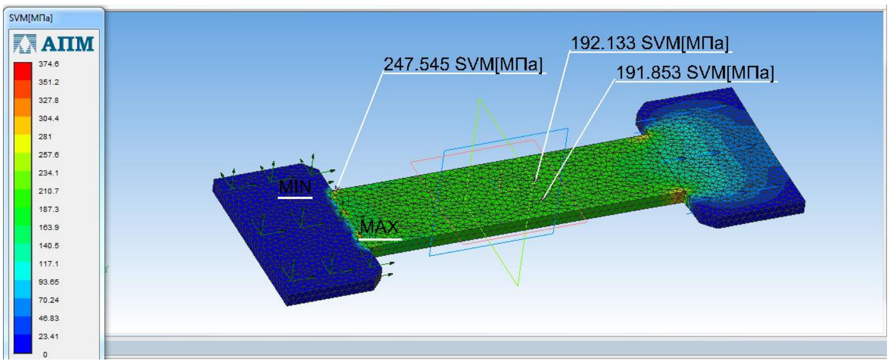
The calculation results charts of stresses and safety factor of the ultimate strength are presented in Fig. 6.



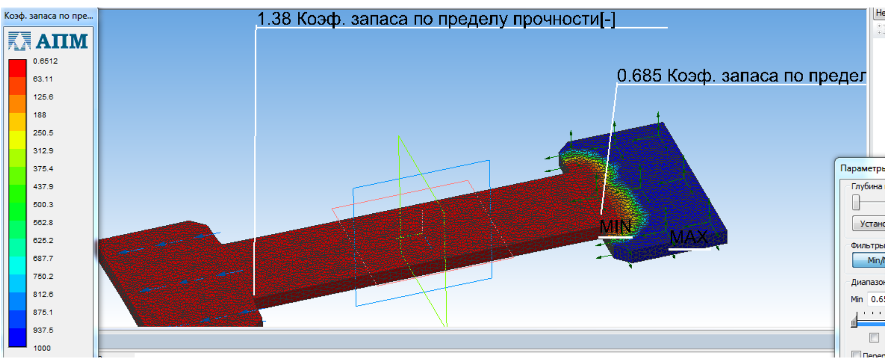
a)



b)



c)



d)

Fig. 6. Results charts: (*a*), (*c*) by stress; (*b*), (*d*) by safety factor

Mechanics

The simulation results suggest that these samples are destroyed in places subjected to maximum stress. Due to the modeling error, the safety factor is other than unity, and the reduction in the size of the finite elements solves this problem. It is also worth saying that this method will be normally implemented when modeling structures operating in tension or compression, since these processes are accompanied mainly by normal stresses. However, during the tests, it has been found that at different elongation factors for the reinforcing materials, delamination occurs along the loading line at the layer boundary due to insufficient interlayer adhesion and high shear stresses.

Discussion and Conclusions. The use of basalt fabrics as a reinforcing substance provides obtaining products with the properties of both glass and carbon plastics. Moreover, such a CM will be slightly more expensive than fiberglass and much cheaper than carbon fiber. Good indicators of the specific strength of basalt, its absolute incombustibility, high impact strength, and resistance to UV radiation should be mentioned. Basalt is a dielectric; therefore, it can be used in the manufacture of cases for radio equipment.

The experiments have shown higher strength characteristics of those CM in which there are more layers of basalt fabric, and glass mat is not used. The use of glass mat as a core causes high interlayer shear stresses, which stimulates interlayer fracture both in tension and in bending. The maximum bending stresses for a sample with a large number of layers of basalt fabric amounted to 261.5 MPa (versus 239 MPa with a smaller number of layers of basalt fabric). In addition, there was a clear superiority in maximum tensile stresses — 190 MPa versus 120 MPa.

The calculation results allow us to state that products made of composite materials (equated to isotropic materials) can be modeled in CAD using the finite element method. It is very important to consider the type of loading on the product, since CM largely have anisotropic properties (the load is applied allowing for the direction of the fibers). So, in multilayer CM from structural fabrics, it is required to direct the loads along the fibers. In addition, it is necessary to consider the interlayer shear, different adhesion between the layers, etc. The main assumption of this method is the "constancy" of the thickness of the material, the number of layers and the order of their location.

The data and method obtained need further research, which will allow us to create a range of composite materials with known characteristics, to simulate them, and to perform the corresponding calculations.

References

1. Nezhizhimov DB. Osobennosti izdelii iz kompozitnykh materialo [Features of products from composite materials]. In: Actual problems of science and technology. Rostov-on-Don: Izd-vo DGTU; 2019. 376–377 p. (In Russ.)

2. Antypas IR, Partko SA, Sirotenko AN. Vliyanie formy gofrirovannogo kartona na amortiziruyushchie svoistva upakovki [Effect of corrugated cardboard shape on the packing damping properties]. Vestnik of DSTU. 2016;16,1(84):36–42. (In Russ.)

3. Antypas IR, D'yachenko AG. Vliyanie soderzhaniya drevesnogo dispersnogo napolnitelya na dolgovechnost' kompozitsionnykh materialov [Effect of wood particulate filler content on durability of composite materials]. Vestnik of DSTU. 2017;17,1(88):67–74. (In Russ.)

4. Antypas IR, D'yachenko AG. Opredelenie kharakteristik komponentov kompozitnykh materialov, prednaznachennykh dlya proizvodstva detalei sel'skokhozyaistvennoi tekhniki [Studies on characterization of composite materials components for part production in agricultural industry]. Vestnik of DSTU. 2017;17,3(90):60–69. (In Russ.)

5. Antypas IR, D'yachenko AG. Izgotovlenie teploizolyatsionnogo materiala i izuchenie ego teplofizicheskikh i mekhanicheskikh svoistv [Production of heat-insulating material and study on its thermophysical and mechanical properties]. In: Proc. 10th Int. Sci.-Pract. Conf. within framework of the 20th Int. Agroindustrial Exhibition "Interagromash-2017". Rostov-on-Don: Izd-vo DGTU; 2017. 182–183 p. (In Russ.)

6. Antypas IR, D'yachenko AG. Ehffekt vlazhnogo travleniya kompozitnogo materiala iz steklovolokna i poliamida na ego svoistva pri izgibe i udare [The effect of wet etching of a fiberglass and polyamide composite material on

its properties under bending and impact]. In: Proc. V Int. Sci.-Pract. Conf. (ITNO-2017). Rostov-on-Don: DGTU-Print; 2017. 26–30 p. (In Russ.)

7. Kharmanda G, Antypas IR. Integration of reliability and optimization concepts into composite yarns. In: Proc. 10th Int. Sci.-Pract. Conf. within framework of the 20th Int. Agroindustrial Exhibition «Interagromash-2017». Rostov-on-Don: Izd-vo DGTU; 2017. 174–176 p.

8. Antypas IR, Partko SA. Sravnenie amortiziruyushchikh svoistv gofrirovannoi kartonnoi upakovki raznoi struktury pri deistvii vertikal'noi nagruzki [Comparison of the cushioning properties of corrugated cardboard packaging of different structures under vertical load action]. In: Proc. 8th Int. Sci.-Pract. Conf. within framework of the 18th Int. Agroindustrial Exhibition «Interagromash-2015». Rostov-on-Don: Izd-vo DGTU; 2015. 232–235 p. (In Russ.)

9. Antypas IR, D'yachenko AG, Savostina TP. Issledovanie vliyaniya dobavok armiruyushchikh volokon na nekotorye mekhanicheskie svoistva perspektivnykh kompozitnykh materialov [Investigation of the effect of reinforcing fiber additives on some mechanical properties of advanced composite materials]. In: Proc. XII Int. Sci.-Pract. Conf. within framework of XXII Agroindustrial Forum of the South of Russia and Exhibition "Interagromash". Rostov-on-Don: Izd-vo DGTU; 2019. 240–244 p. (In Russ.)

10. Antypas IR, D'yachenko AG. Modelirovanie, izuchenie i izgotovlenie stoiki kul'tivatora iz kompozitnykh materialov [Modeling, studying and manufacturing a cultivator rack from composite materials] Mordovian University Bulletin. 2018;28 (3):366–378. (In Russ.)

11. Al-Jeebory AA, Al-Mosawi AI, Abdul Allah SA. Effect of Percentage of Fibers Reinforcement on Thermal and Mechanical Properties for Polymeric Composite Material. The Iraqi Journal for Mechanical and Materials Engineering. 2009 17–18 May, Special Issue:70–82.

12. Vincenzini P, Singh M. Advanced Inorganic Fibrous Composites V. Advances in Science and Technology. 2006;50:97–106.

13. Dixit A, Mali HS. Modeling techniques for predicting the mechanical properties of woven-fabric textile composites: a Review. Mechanics of Composite Materials. 2013;49(1):1–20.

Submitted 19.12.2019

Scheduled in the issue 03.02.2020

About the authors

Amer Karnoub, Guest Researcher at the Physics and Technology Laboratory, Department of Materials, ETH Zurich (Rämistrasse 101, 8092 Zurich, Switzerland), Cand.Sci. (Eng). ORCID: http://orcid.org/0000-0002-9824-7364 amerkarnoub@gmail.com

Nezhizhimov, Danil B., graduate student of the Machine Design Principles Department, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF). ORCID: https://orcid.org/0000-0002-1036-5746 nezhizhimov96@mail.ru

Shirinyan, Karen S., graduate student of the Machine Design Principles Department, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF). ORCID: https://orcid.org/0000-0001-7697-6411 shirinyan.karen@yandex.ru

Claimed contributorship

A. Karnoub: academic advising, research objectives and tasks correction, analysis of the test results, analysis of the calculation results, the text revision, correction of the conclusions. D. B. Nezhizhimov: basic concept formulation, research objectives and tasks setting, procurement of materials, prototyping, testing, text preparation, analysis of tests and calculations, formulation of conclusions. K.S. Shirinyan: consultations in the formulation of the basic concept, consultations in setting the goals and objectives of the study, testing, consultation in the calculation.

All authors have read and approved the final manuscript.